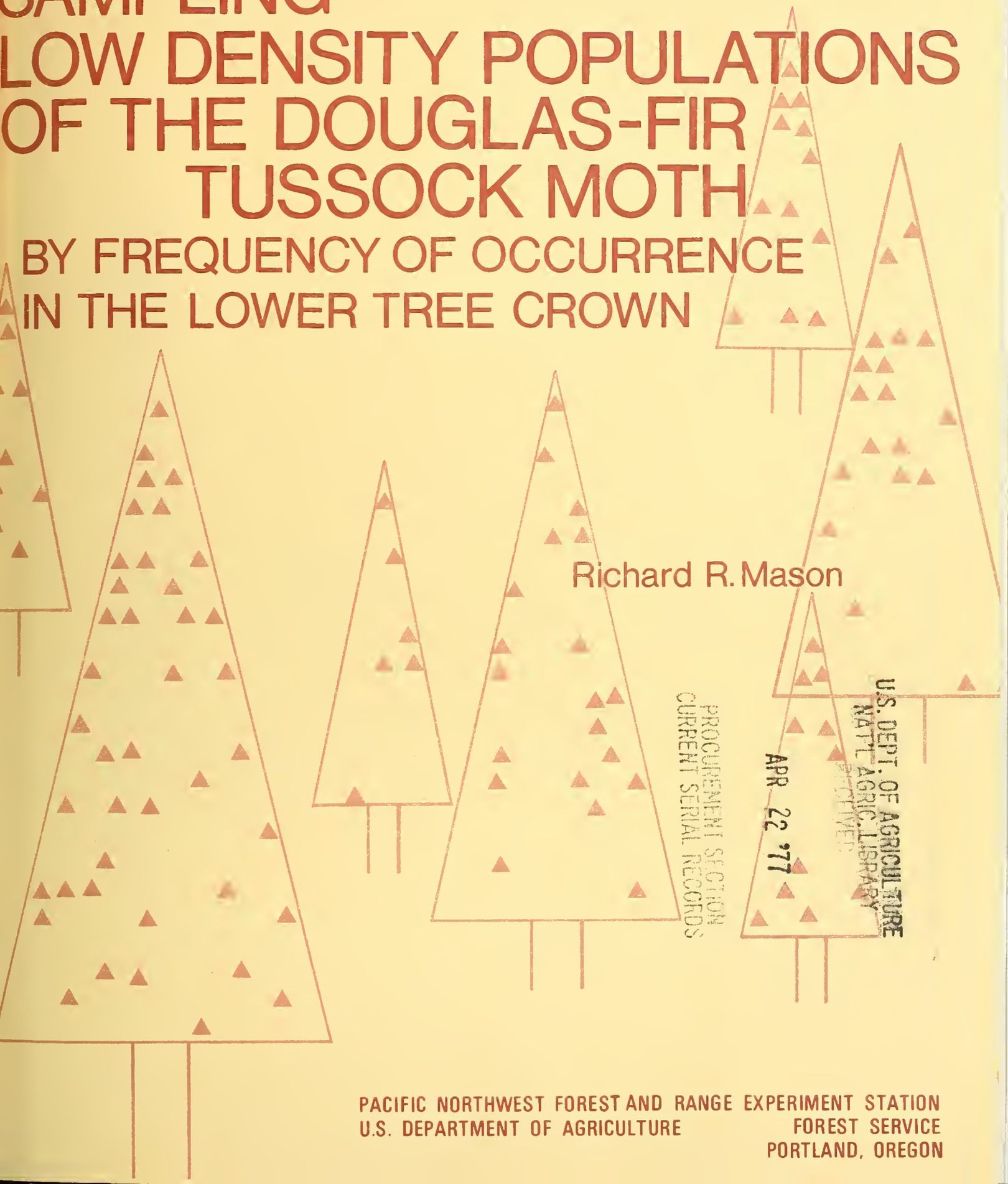
1977
USDA FOREST SERVICE RESEARCH PAPER PNW-216

SAMPLING LOW DENSITY POPULATIONS OF THE DOUGLAS-FIR TUSSOCK MOTH

BY FREQUENCY OF OCCURRENCE IN THE LOWER TREE CROWN



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Tree diagrams on cover illustrate the expected vertical distribution over the tree of small tussock moth larvae (shaded symbols). The distributions were generated from random numbers according to a 4:2:1 probability of occurrence from top to bottom.

Sampling Low Density Populations of the Douglas-fir Tussock Moth by Frequency of Occurrence in the Lower Tree Crown

Reference Abstract

Mason, Richard R.
1977. Sampling low density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower tree crown. USDA For. Serv. Res. Pap. PNW-216, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A new method is described for rapidly estimating the larval density of low-level populations. Densities of 1.0 or fewer larvae per 1,000 sq in (0.64 sq m) of branch area in the midcrown of host trees can be predicted from the proportion of sample units that are infested in the lower tree crown. This procedure is an improvement over the conventional midcrown sampling method because observations can be made in the more accessible lower crown without clipping and measuring branches. The technique is especially applicable to low-level populations which require the examination of large amounts of foliage to estimate larval density.

KEYWORDS: Population sampling (insect), insects, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

RESEARCH SUMMARY

Research Paper PNW-216

1977

Density of larvae on host tree foliage has become the accepted index for evaluating tussock moth populations. Density is usually estimated in outbreaks by sampling midcrown foliage with a pole pruner and basket. However, such a method is impractical for sampling low-density populations where larvae are sparsely distributed in the foliage and rarely encountered on sample branches. It is important to be able to measure low-density populations because potential outbreaks can be detected at least 2 years in advance of tree damage by observing annual trends in numbers of small larvae.

A new method has been developed and described for sampling early instars in low-density populations. A large amount of foliage can be examined quickly and easily because all data are collected from accessible lower crown branches and branch area does not have to be measured. Selected sample branches within reach are beaten in place over a portable drop cloth on which dislodged larvae can be observed.

For average sample unit sizes the number of larvae in low-density populations of less than 1.0 per 1000 in^2 (0.64 m^2) follows a Poisson distribution. Using the theoretical relationship from this distribution mean density of larvae in the lower crown can be approximated from the proportion of samples infested. Larval density in the midcrown is calculated by correcting the lower crown density according to the expected vertical distribution of larvae in the tree. The model derived from this procedure is $\hat{M} = -4 \ln(1 - p_x)$, where $\hat{M}$ is the midcrown density of early instars and p_x is the proportion of infested 3-branch samples in the lower crown.

This sampling method has been field tested in low-density populations for two seasons and found to produce results comparable to the conventional method of sampling foliage in the midcrown with a pole pruner.

Contents

Introduction

Conventional methods for sampling larvae of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) involve examining and measuring branches removed from the middle one-third of host trees with a pole pruner and basket (Mason 1970). Density of the population is expressed in terms of larvae per 1,000 in^2 (0.64 m^2) of branch area. This method is adequate for estimating population densities in sub-outbreak and outbreak conditions where larval density exceeds 1.0 larva per 1,000 in^2 (0.64 m^2) of branch area. Conventional sampling is unsatisfactory for very low populations with a density that may be far below the 1.0 level. Tussock moth densities are apparently low most of the time and, as a result, are not easily quantified by normal sampling procedures.

In population studies, sample plots usually consist of 12 to 15 trees from which 5,000 to 8,000 in^2 (3.2-5.1 m^2) of branch area or about 500 in^2 (0.32 m^2) per tree are removed for examination. At this rate a very large number of trees must be sampled to quantify low density populations. As illustrated below, when population density is less than 0.1, the average number of trees required to sample a single larva is completely impractical by present standards.

Number larvae per 1,000 in^2 (0.64 m^2)	Average branch area per larva	Average number sample trees per larva sampled
1	1,000 in^2 (0.64 m^2)	2
.1	10,000 in^2 (6.4 m^2)	20
.01	100,000 in^2 (64.0 m^2)	200
.001	1,000,000 in^2 (640 m^2)	2,000

A modified procedure is needed for sampling low density populations. To be of practical use, such a procedure must meet at least two criteria: (1) larval density must be expressed in standard units of branch area and, (2) a sample crew must be able to examine large amounts of foliage on each plot within a reasonable amount of time. Such a sampling method is described in this paper. Most data discussed are for small larvae (1st-2nd instars). The method may also have application for sampling older larvae.

The Sampling Approach

The first criterion of standardization can be satisfied by a basic relationship that exists between the mean density of larvae and the proportion of sample units that contain one or more larvae. When larvae are abundant in an area, they will appear in a greater proportion of the samples than when they are rare. The exact form of this relationship depends on the size of the sample unit and the frequency distribution of data. The relationship can be determined by regression analysis or by fitting a theoretical mathematical distribution to field data.

Once the relationship is known, mean density can be estimated from the proportion of infested samples. The advantage of the method is that branch area need not be measured nor larvae counted. Sample units are recorded as infested or not infested. The general technique has been developed and recommended for sampling other insects (Gerrard and Chiang 1970, Wilson and Gerrard 1971) and for measuring vegetation (Dice 1952).

The second criterion for rapid foliage examination can be satisfied by sampling low tree branches within reach of the average person. This eliminates the need for aerial sampling equipment and permits a great deal more foliage to be examined in the same amount of time than by the conventional midcrown method. The success of sampling the lower crown assumes that density of tussock moth larvae in that lower stratum is a satisfactory index which can be calibrated with population density over the entire tree.

Frequency of Infested Sample Units

Sample data collected on plots from several locations in the West over the last 9 years were used to determine the needed relationship between mean density and proportion of infested samples. Fortunately, data were available from 50 plots where density of small larvae was less than 1.0 per 1,000 in^2 and could be used to calculate this relationship for low density populations of tussock moth.

The plots ranged in size from 10 to 40 trees. The primary sample unit was three 18- to 22-in (46-56 cm) branches from the midcrown, i.e. the crown originating from the middle one-third of the bole, of each tree. Density of the larval population was calculated in the conventional manner by

$$M = 1000 \frac{1}{n} \sum_{i=1}^{n} \left(\frac{y_i}{a_i}\right); \qquad (1)$$

where

M = mean number of larvae/1,000 in^2 of branch area in the midcrown.

y_i = number of larvae on a three-branch sample unit from the midcrown of tree i.

a_i = in^2 of branch area sampled in tree i.

n = number of trees sampled.

The proportion, p_y, of midcrown sample units infested was calculated by

$$p_y = r/n \qquad (2)$$

where r is the number of sample units possessing one or more larvae.

The relationship of M to p_y is plotted in figure 1. A linear regression fitted to the data, shown by the broken line, accounts for 89 percent of the variation. Midcrown larval density over the range of these data can be estimated by the regression equation

$$\hat{M} = .007 + 2.109\ p_y. \qquad (3)$$

The slope of 2.109 means that when infested sample units contain only one larva, which is usually the case on low density plots, the three-branch sample unit averaged 474 in^2 (0.30 m^2). The regression line does not pass through the origin, and it would probably tend to overestimate very low densities. The line can be forced through the origin with little change in the slope coefficient so that larval density may be better estimated by

$$\hat{M} = 2.152\ p_y. \qquad (4)$$

The occurrence of larvae on samples at low densities is a relatively rare event and can also be shown to follow a Poisson distribution where variance equals the mean. Although agreement with this distribution is the accepted test for randomness, it does not necessarily mean that larvae at low densities are actually randomly distributed in the foliage. Size of the sample unit has an important effect on tests for distribution, and the branch samples in this case are probably too small to detect any aggregation in the population. Nevertheless, larval density on a plot can also be calculated from the theoretical distribution of the Poisson variables (Fisher 1941) by

$$\bar{y} = -\ln(1-p_y); \qquad (5)$$

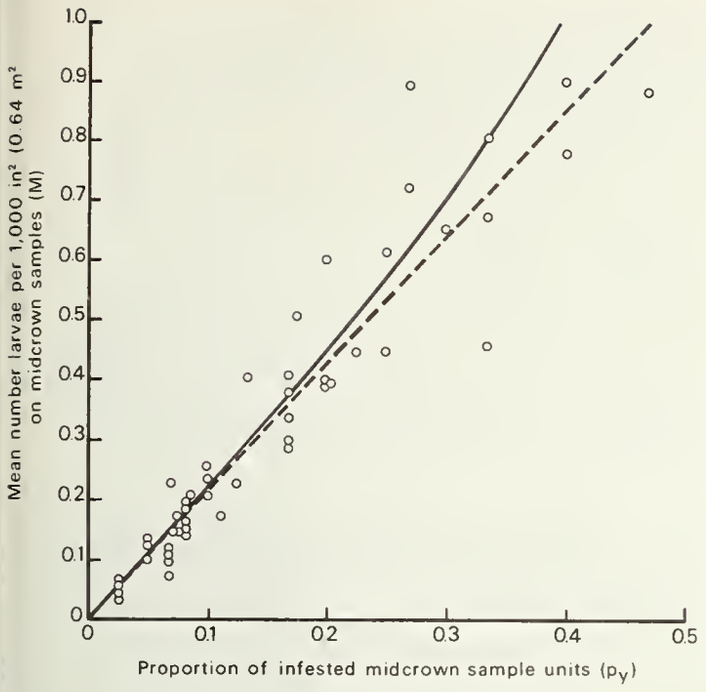

Figure 1.--Relationship between density of small tussock moth larvae (M) and proportion of infested sample units (p_y) in the midcrown.

where

$\bar{y}$ = mean density of larvae/sample unit in the midcrown.

ln(a) = natural logarithm of a.

Since the average sample unit size is about 500 in^2 (0.32 m^2), larval density per 1,000 in^2 (0.64 m^2) can be approximated by

$$\hat{M} = -2 \ln(1-p_y). \qquad (6)$$

This relationship is shown by the solid line in figure 1. Because of its theoretical base, equation (6) is probably a better model than equation (4) for estimating density below the range of the data shown in figure 1. Neither equation is a completely satisfactory model for density levels above 1.0 when the measured distribution of larvae is non-random.

Lower Crown Density as a Population Index

The only published study of larval distributions in the tree crown was conducted in a small tussock moth outbreak in the Corral Creek area of the Modoc National Forest in 1966 (Mason 1970). In this investigation, larvae were found in different concentrations in all portions of the crown. The average distribution of all ages of larvae from top to bottom, for the same amount of foliage sampled, approximated a 4:2:1 ratio; i.e. twice and four times the density of larvae occurred on middle and upper crown samples as on lower crown samples. Middle crown samples were judged to be most representative of the whole tree and have since been used successfully as the standard for determining larval density.

Lower crown branches also clearly contain a fraction of the larval population and, although not as representative of the tree as midcrown branches, can be used to obtain a population index. Based on results of the earlier studies for all ages of larvae, we would expect populations of early instars in the lower crown to average about one-half the density of those in the standard middle crown. Late instars may have almost the same density in both crown levels due to a shift in distribution prior to pupation. For only first- and second-instar larvae, the actual ratio of means (R) of midcrown density (M) to lower-crown density (L) at Corral Creek averaged 2.41 over eight plots. The median R was 2.04 which, in this case, is probably a better measurement of central tendency.

M	L	R
---Larvae per 1,000 in^2 (0.64 m^2)---		
61.2	38.5	1.59
62.2	11.7	5.32
65.6	59.0	1.11
21.6	11.5	1.88
30.2	13.0	2.32
54.6	15.8	3.46
14.1	10.3	1.37
58.0	26.2	2.21

Mean R $\pm$ SE = 2.41 $\pm$ .49

Median R = 2.04

These data are from an outbreak with relatively high density populations. The ratios could differ in low density situations. Considering the dispersal habits of early instar larvae, there seems to be no compelling reason why similar R values would not be expected.

Estimating Population Density from Lower Crown Samples

If we use the same rationale for developing equation (6), density of larvae per 1,000 sq in^2 (0.64 m^2) in the crown from the lower one-third bole (L) can be estimated by

$$\hat{L} = -2 \ln(1-p_x); \qquad (7)$$

where

p_x = estimated proportion of sample units in the lower crown with one or more larvae.

Equation (7) assumes that the same frequency distribution of larvae and sample unit size apply in the lower crown as in the middle crown where data for developing the relationships were originally collected. Although larval density is less, there is no reason to expect a different distribution pattern of larvae in the lower crown. The size of branch samples examined in the lower crown, however, must be controlled to approximate the size of normal midcrown samples.

By accepting lower crown density as an index, midcrown density can now be estimated by

$$\hat{M} = R\hat{L}, \qquad (8)$$

or from the proportion of infested lower crown sample units by

$$\hat{M} = -2 R \ln(1-p_x). \qquad (9)$$

Without additional subsampling at each location, which is impractical, an average value of R must be assumed. A precise estimate may be unnecessary due to the relatively small effect of R over the range of low densities that we expect to measure. From what is presently known about the vertical distribution of larvae, a reasonable value of R for early instars seems to be about 2.0. Due to downward migration of older larvae, however, we suspect that R decreases through the season and may approach 1.0 by the time of pupation.

After substituting 2.0 for R in equation (9) the density of early instars can be estimated by

$$\hat{M} = -4 \ln(1-p_x). \qquad (10)$$

Equation (10) is graphed on a logarithmic scale in figure 2 to give expected densities for different values of p_x.

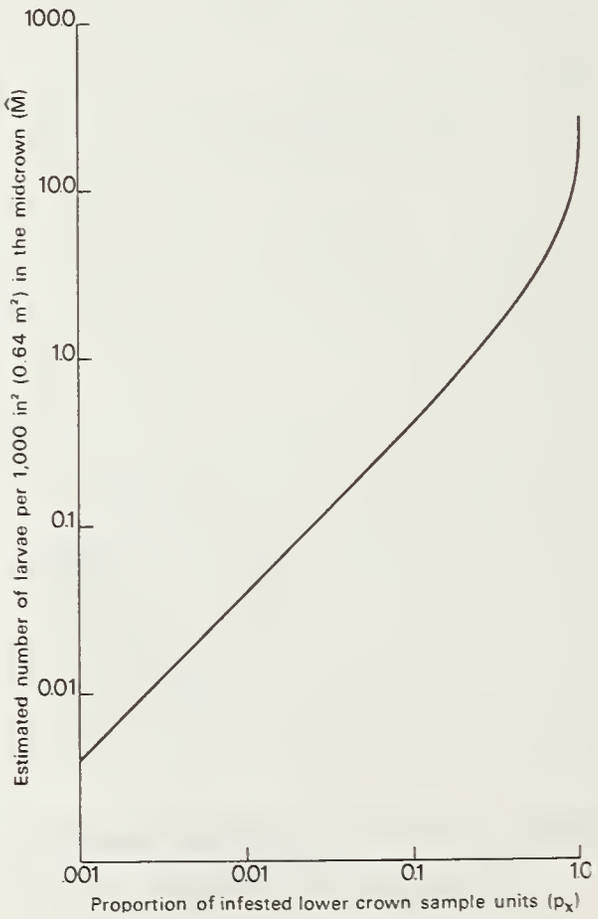

Figure 2.--Predicted relationship between proportion of lower crown sample units infested (p_x) and density of small tussock moth larvae in the midcrown ($\hat{M}$).

The equation shows that at midcrown densities of 1.0 or less larvae per 1,000 in^2 (0.64 m^2), fewer than 22 percent of the lower crown sample units will be infested. At midcrown densities of about 20 larvae per 1,000 in^2 (0.64 m^2) almost all lower crown sample units will have larvae. The model is most applicable to densities below the 0.1 level which cannot be estimated by any other practical method; but it should also be satisfactory for estimating higher densities up to at least 5.0 larvae per 1,000 in^2 (0.64 m^2). Theoretically, the model should tend to slightly underestimate densities over 1.0 because the Poisson distribution assumes randomness and does not consider that the aggregation of larvae on this sample unit size increases at higher densities (Dice 1948). Proportions and calculated densities for three values of R are listed in table 1 for easy conversion.

Field Application and Validation

An appealing advantage of sampling lower crown foliage is that branches can be examined in place without removing them from the tree. This is done by beating the foliage of three sample branches per tree over a hand-held drop cloth (fig. 3). Because of the assumption of similarity in sample unit size, care must be taken that the branches beaten are similar in size to those normally sampled in the midcrown. The beating cloth should not be placed under more than about 22 in (56 cm) of a branch. The only information noted for the three-branch sample unit is whether or not it contains at least one tussock moth larva. A larval count is not necessary because frequency of occurrence is determined only by presence, or absence, on the sample unit. If a larva is found on the first branch there is no reason to examine the other two.

Figure 3.--Sampling tussock moth larvae on lower crown foliage by beating branches over a hand-held drop cloth. Dimensions of the cloth are 24 x 48 in (61 x 123 cm). The cloth is supported in the corners by aluminum cross members. The photos illustrate the technique of sampling a range of heights in the lower crown with the portable drop cloth.

Table 1--*Table for converting proportion of infested lower crown samples* (p_x) *to density of larvae at midcrown* ($\hat{M}$). *Densities are calculated from* $\hat{M} = -2R \ln(1-p_x)$ *for three values of* R.[1/]

p_x	$\hat{M}$			p_x	$\hat{M}$		
	R = 1.0	R = 1.5	R = 2.0		R = 1.0	R = 1.5	R = 2.0
	No. per 1000 in^2 (0.64 m^2)				No. per 1000 in^2 (0.64 m^2)		
.001	.002	.003	.004	.31	.74	1.11	1.48
.002	.004	.006	.008	.32	.77	1.16	1.54
.003	.006	.009	.012	.33	.80	1.20	1.60
.004	.008	.012	.016	.34	.83	1.25	1.66
.005	.010	.015	.020	.35	.86	1.29	1.72
.006	.012	.018	.024	.36	.89	1.34	1.78
.007	.014	.021	.028	.37	.92	1.39	1.85
.008	.016	.024	.032	.38	.96	1.43	1.91
.009	.018	.027	.036	.39	.99	1.48	1.98
.01	.02	.03	.04	.40	1.02	1.53	2.04
.02	.04	.06	.08	.41	1.06	1.58	2.11
.03	.06	.09	.12	.42	1.09	1.63	2.18
.04	.08	.12	.16	.43	1.12	1.68	2.25
.05	.10	.15	.20	.44	1.16	1.74	2.32
.06	.12	.19	.25	.45	1.20	1.79	2.39
.07	.15	.22	.29	.46	1.23	1.85	2.46
.08	.17	.25	.33	.47	1.27	1.90	2.54
.09	.19	.28	.38	.48	1.31	1.96	2.62
.10	.21	.32	.42	.49	1.35	2.02	2.69
.11	.23	.35	.47	.50	1.39	2.08	2.77
.12	.26	.38	.51	.51	1.43	2.14	2.85
.13	.28	.42	.56	.52	1.47	2.20	2.94
.14	.30	.45	.60	.53	1.51	2.27	3.02
.15	.32	.49	.65	.54	1.55	2.33	3.11
.16	.35	.52	.70	.55	1.60	2.40	3.19
.17	.37	.56	.74	.56	1.64	2.46	3.28
.18	.40	.60	.79	.57	1.69	2.53	3.38
.19	.42	.63	.84	.58	1.74	2.60	3.47
.20	.45	.67	.89	.59	1.78	2.67	3.57
.21	.47	.71	.94	.60	1.83	2.75	3.67
.22	.50	.75	.99	.61	1.88	2.82	3.77
.23	.52	.78	1.04	.62	1.94	2.90	3.87
.24	.55	.82	1.10	.63	1.99	2.98	3.98
.25	.58	.86	1.15	.64	2.04	3.06	4.09
.26	.60	.90	1.20	.65	2.10	3.15	4.20
.27	.63	.94	1.26	.66	2.16	3.24	4.32
.28	.66	.99	1.31	.67	2.22	3.33	4.43
.29	.68	1.02	1.37	.68	2.28	3.42	4.56
.30	.71	1.07	1.43	.69	2.34	3.51	4.68
				.70	2.41	3.61	4.82

[1/] R = 2.0 is recommended for sampling 1st to 2d instars (small larvae), R = 1.5 for 3d to 4th instars (medium larvae), and R = 1.0 for 5th to 6th instars (large larvae).

A population density in the range of 0.1 to 1.0 larvae per 1,000 in^2 (0.64 m^2) will require a sample size of at least 100 trees for an estimate of p_x. Larger sample sizes will be needed for larval densities that are less than 0.1. The practical limits to sampling by this procedure are probably around 0.01 although estimates of lower density levels are possible.

Standard procedures for selecting sample trees and canvassing a plot area have not yet been fully developed. Sampling is restricted to trees with branches in the lower stratum that can be reached by hand. All trees in this category should be included in the sample as one proceeds through the area. To prevent bias, only lower branches should be sampled even though the tops of small understory trees can be reached. A sampling crew can satisfactorily cover a 2- to 5-acre (.4-2.0 ha) area by starting at a central point and radiating out in different directions. To cover a larger area, which may be necessary in very low density situations, a crew may have to proceed in the same direction along a swath through the area.

This modified method of sampling was tested on relatively low density populations at several field locations in 1975 and 1976. Results were compared with conventional midcrown sampling of early instars at the same general locations, but on different trees. Larval density was estimated from 15 sample trees using the conventional method, equation 1, and from 75 to 100 different trees with the lower crown method, equation 10.

Data from both sampling methods are compared graphically in a scatter diagram shown in figure 4. The comparison shows that density estimates from the two methods are similar, evidenced by the scatter of data points along the 45-degree slope of equality. A simple correlation analysis

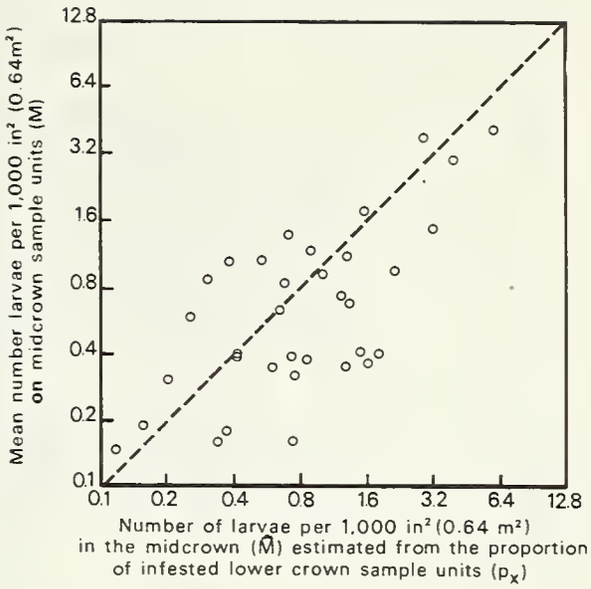

Figure 4.--Comparison of midcrown densities of small larvae estimated from midcrown samples and from proportion of infested lower crown samples.

performed on the two sets of data showed that the model using p_x to estimate M accounted for 69 percent of the observed variation ($r = 0.831$; $n = 34$). This suggests that within the range of these data comparable results could be obtained by using either sampling method. Additional estimates of R were calculated for 1st-2d instars from the ratio $M/\hat{L}$ on each plot. These averaged $1.81 \pm .21$ (SE) over 34 plots and, thus, generally supported the value of R used in equation (10).[1/] Such encouraging results indicate that lower crown frequency sampling has good potential for estimating larval densities below the range from which previous data have been collected.

[1/] The average value of R for 3'rd-4'th instars on 7 plots was lower, $.98 \pm .16$ (SE), which suggests that in low density populations there is a change in vertical distribution as larvae mature.

Acknowledgments

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The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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